Cleaning and Cleanrooms

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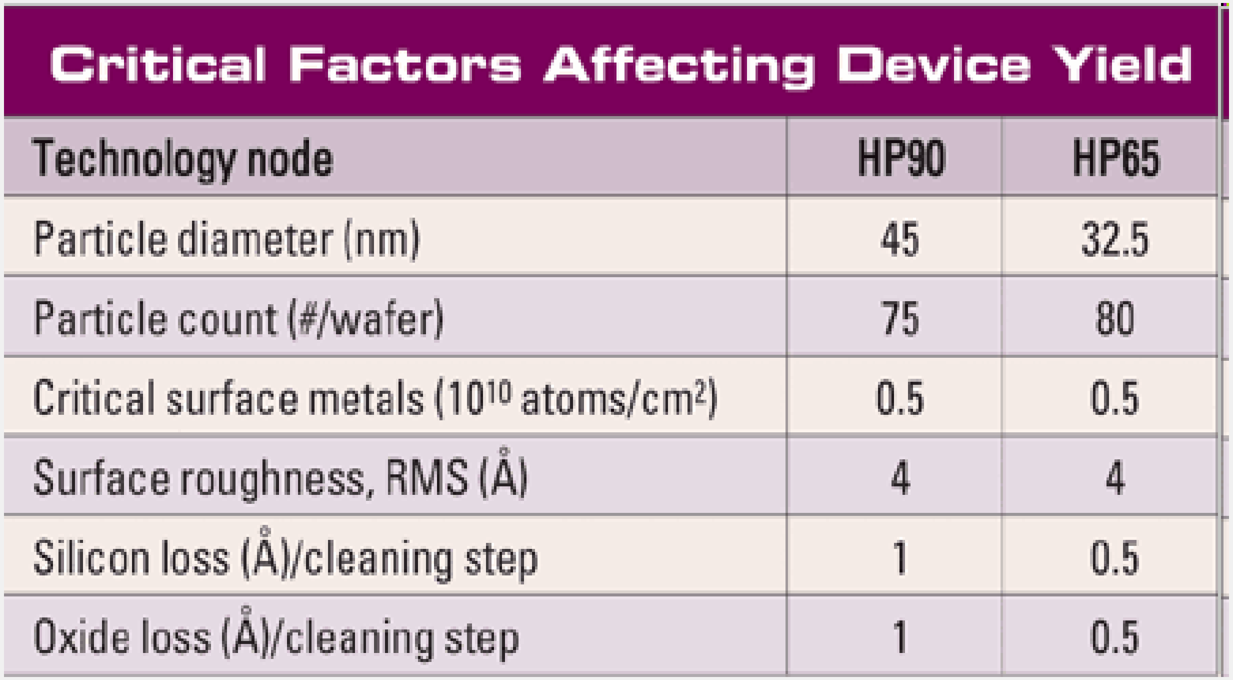
Chapters 12, 35

Previous lecture

- Thin films:
  - deposition methods
  - properties
  - released films
  - post deposition treatment

Critical factors of device yield



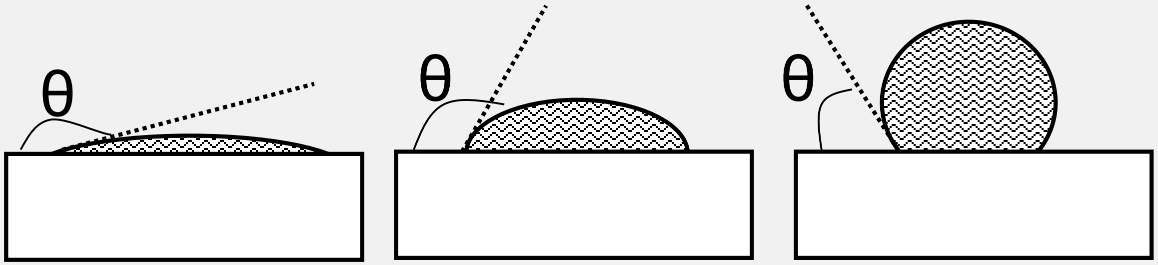
Critical Factors Affecting Device Yield

Technology node	HP90	HP65
Particle diameter (nm)	45	32.5
Particle count (#/wafer)	75	80
Critical surface metals (10^{10} atoms/cm^2)	0.5	0.5
Surface roughness, RMS (Å)	4	4
Silicon loss (Å)/cleaning step	1	0.5
Oxide loss (Å)/cleaning step	1	0.5

Wafer cleaning and surface preparation

- Wafer cleaning
  - removal of added contamination
  - chemically clean
  - particle-free
- Surface preparation
  - known surface condition
  - independence of previous step
  - independence of wait time

Contact angle and wettability



wettable, hydrophilic

non-wettable, hydrophobic

superhydrophobic

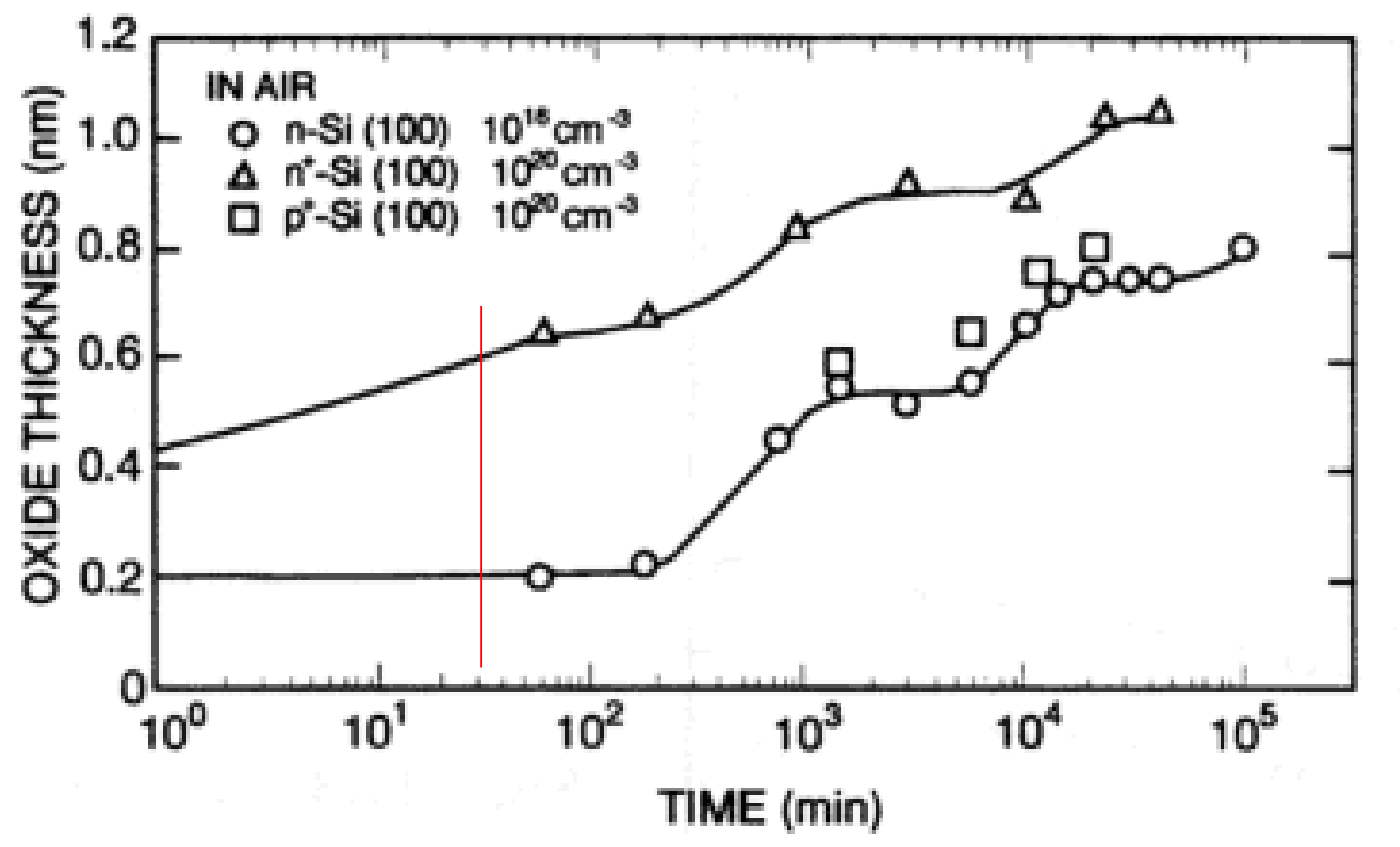
Contamination forms and harmfulness

- -particles –> patterning, growth
- -metals (atomic and ionic contamination) –> Si electronic properties, oxide quality
- -organics (molecules and molecular films) –> contact resistance, growth
- -native oxide (nanometer films) –> growth, contact degradation
- -surface roughness –> growth, patterning

Contamination sources

- -reaction (by)products in e.g. etching or CVD
- -flaking of films from chamber walls
- -sputtering of wall materials
- -wafer transport: mechanical handling, chucking/clamping
- -jigs: wafer boats (quartz), polypropylene/teflon cassettes
- -wafer itself: chipping and breakage
- -maintenance: cleaning of chambers and transport mechanisms

Waiting time and native oxide



Wet cleaning solutions

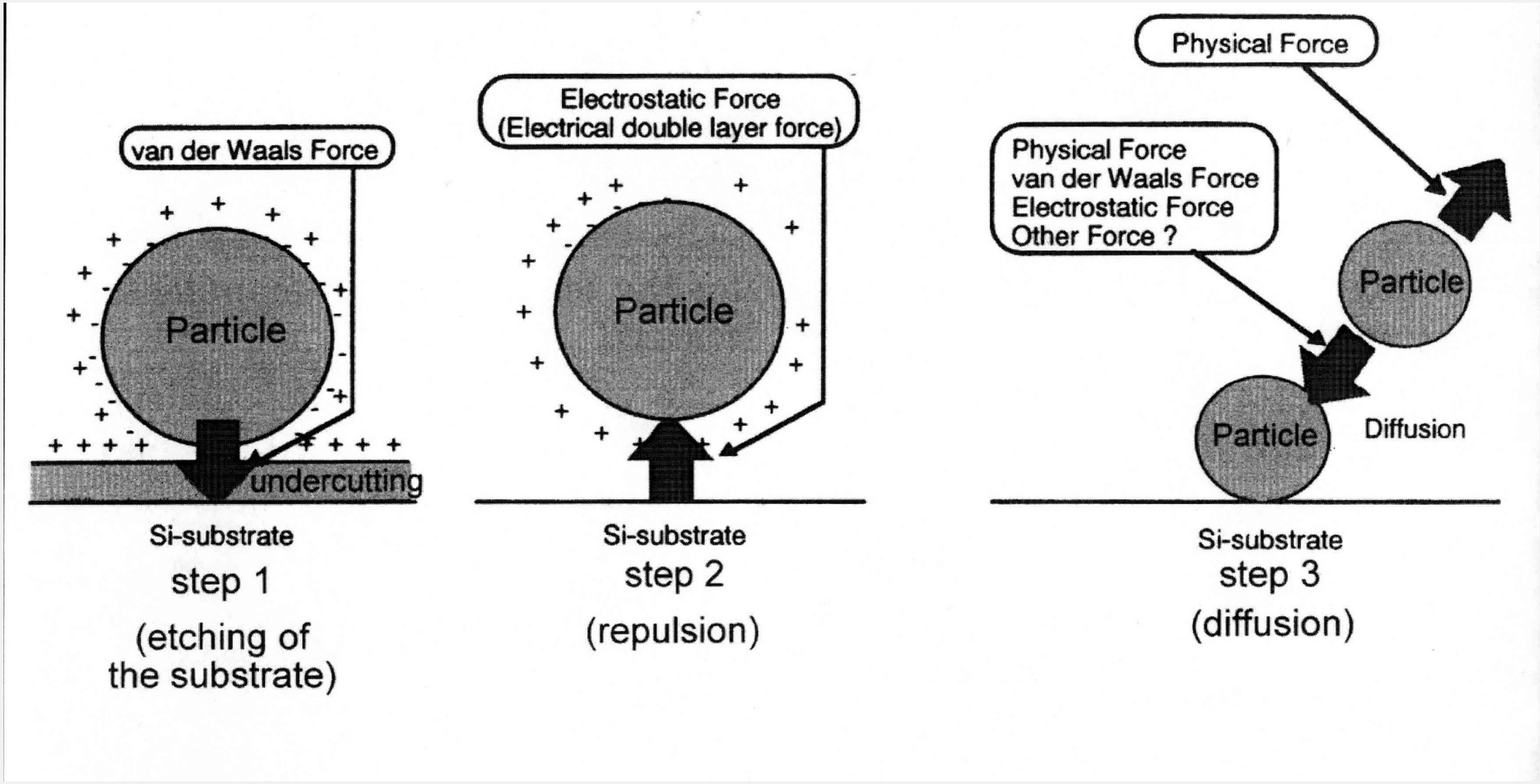
- **RCA-1** **$NH_4OH:H_2O_2:H_2O$ (1:1:5)**
  - SC-1, standard clean; 50-80ºC, 10-20 min
  - APM; ammonia-peroxide mixture

- **RCA-2** **$HCl:H_2O_2:H_2O$ (1:1:6)**
  - SC-2; standard clean-2; 50-80ºC, 10-20 min
  - a.k.a. HPM, hydrogen chloride-peroxide mixture

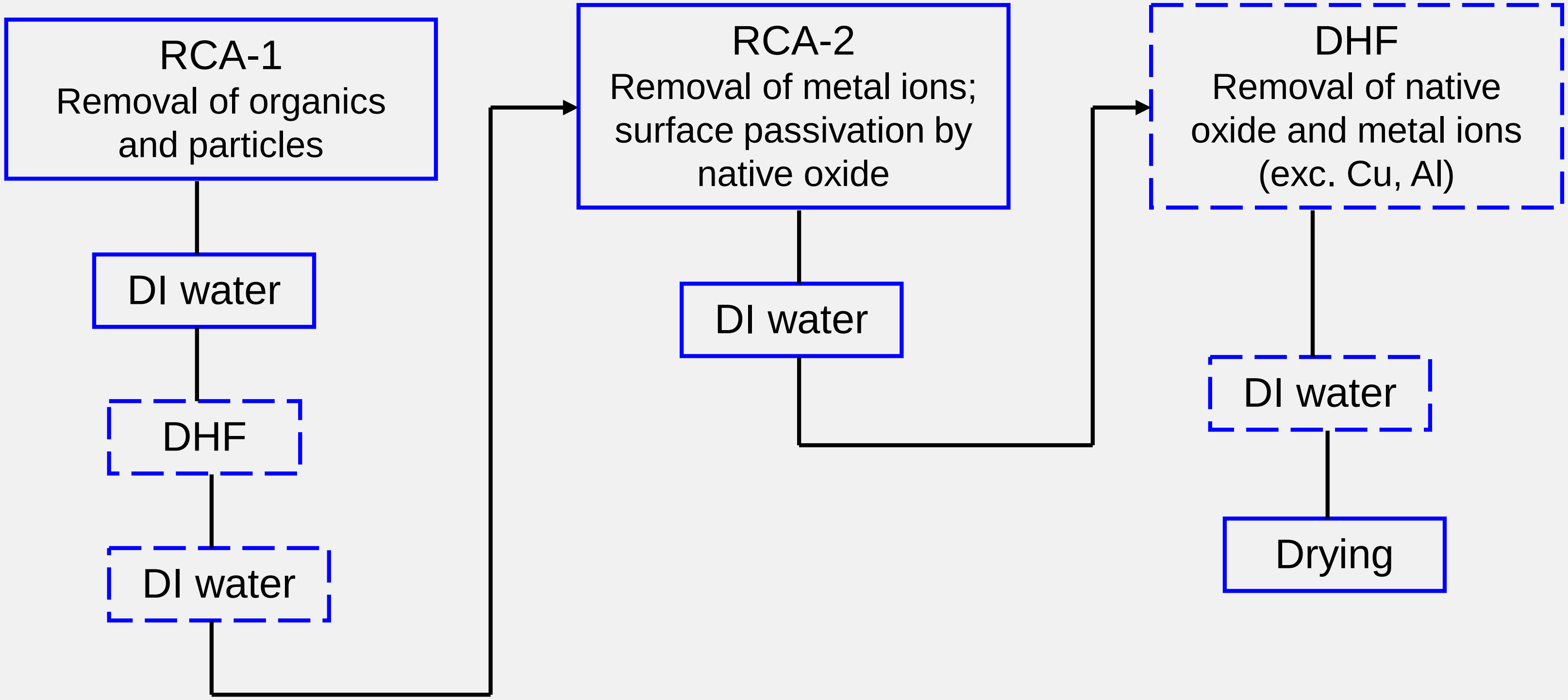
- **SPM** **$H_2SO_4:H_2O_2$ (4:1)**
  - sulphuric peroxide mixture; 120ºC, 10-20 min
  - a.k.a. Piranha
- **DHF (dilute HF)** **$HF:H_2O$ (1:100-1000)**

  room temperature, 1 min

Particle detaching



Cleaning procedure



RCA-1
Removal of organics and particles

DI water

DHF

DI water

RCA-2
Removal of metal ions; surface passivation by native oxide

DI water

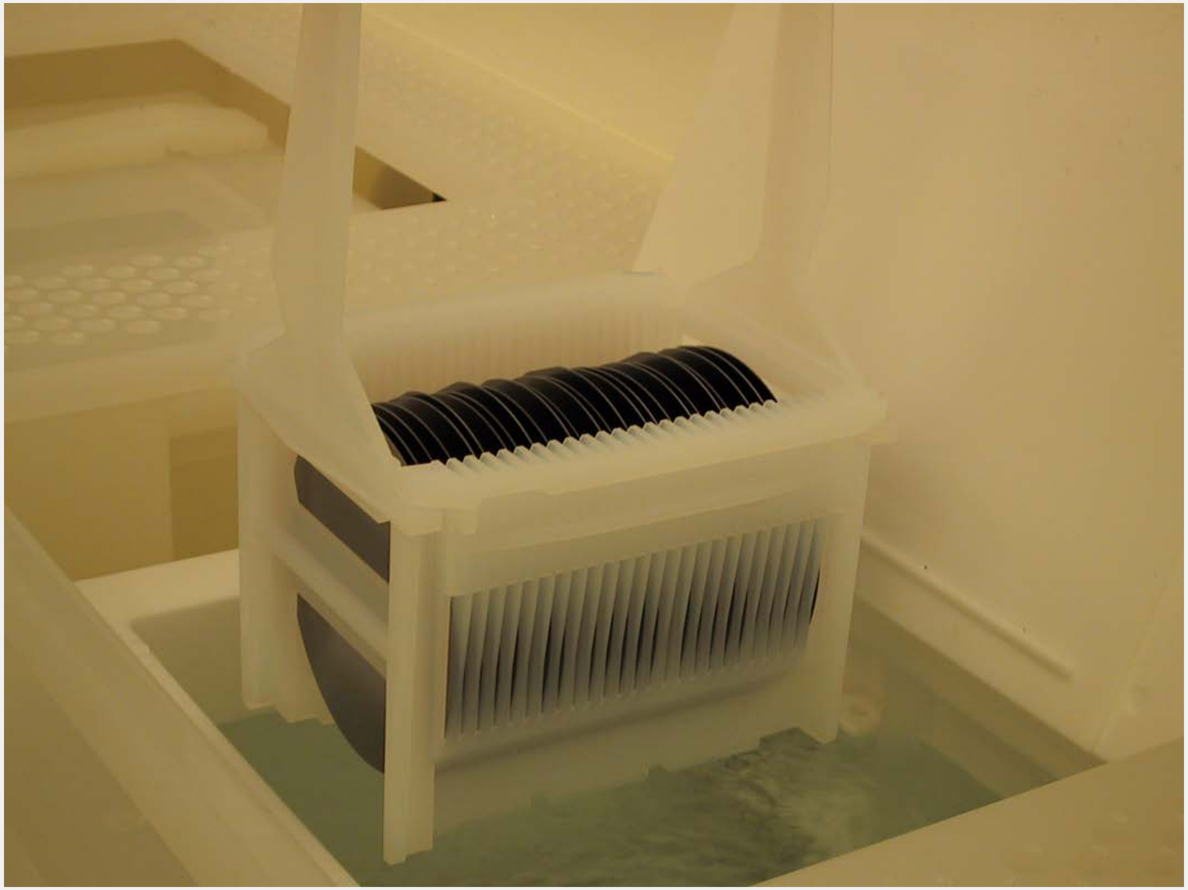
DHF
Removal of native oxide and metal ions (exc. Cu, Al)

DI water

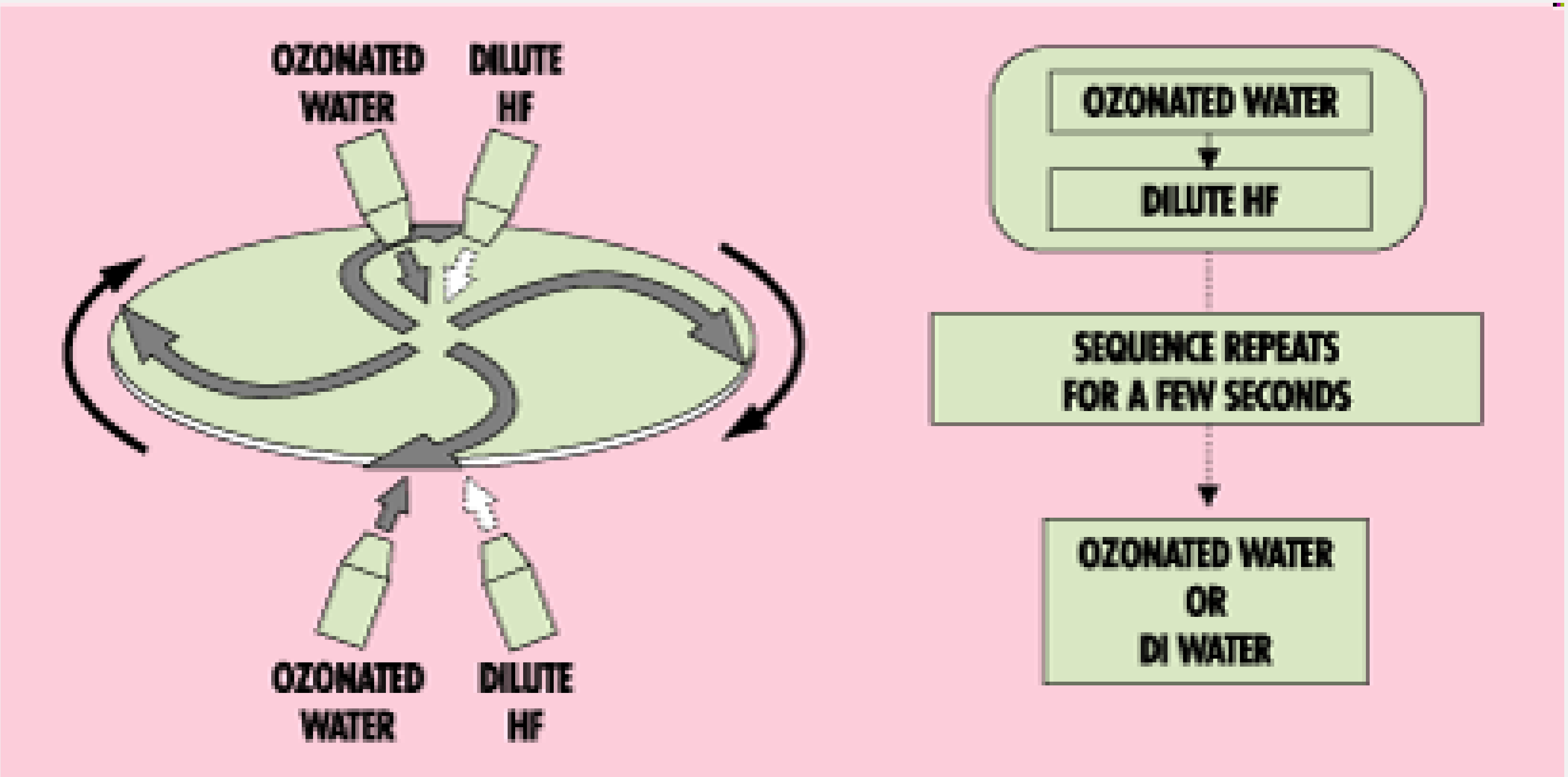
Drying

Wet bench

Wafer cassette

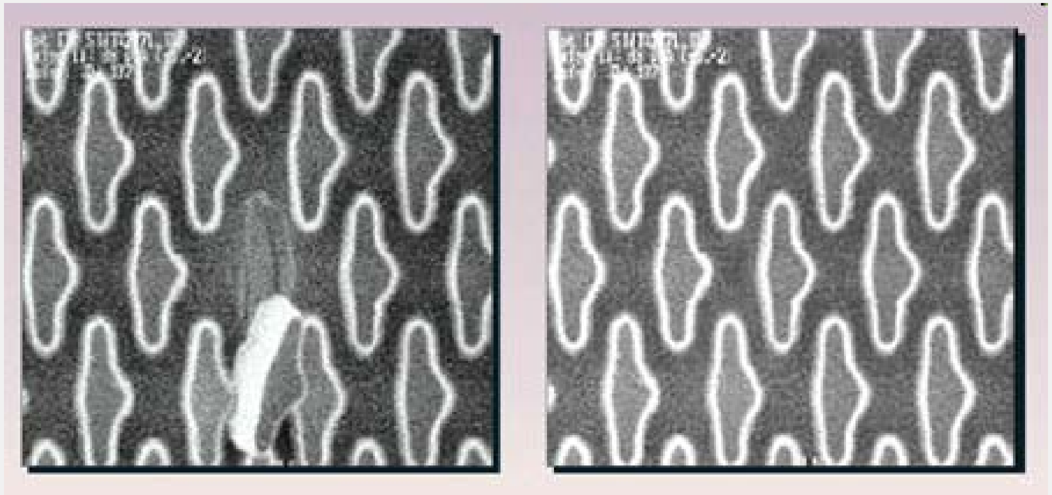


Single wafer cleaning



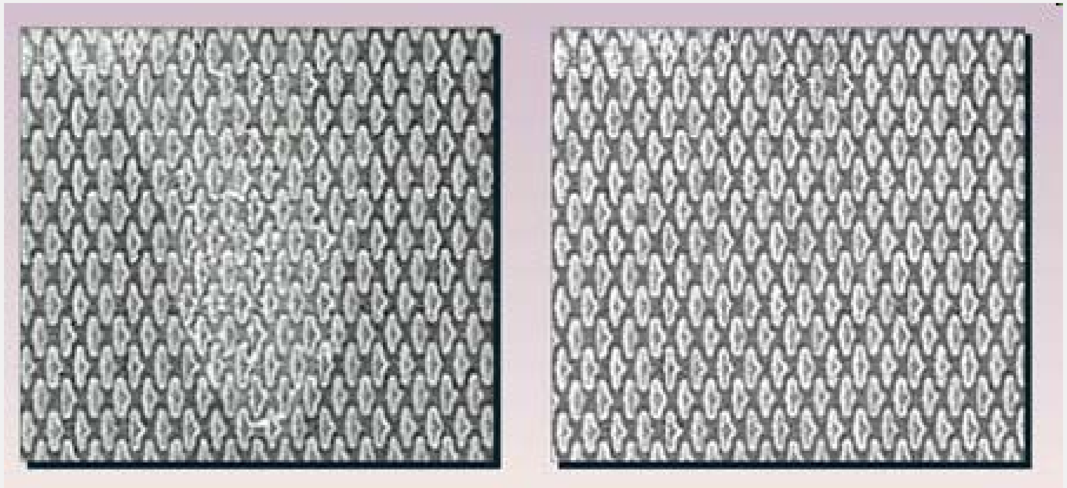
The repetitive use of ozonated water and dilute HF in the SCROD process

Clean defects



Megasonic cleaning in a batch immersion tool shows megasonic-induced damage of a 92 nm STI 300 mm wafer after an SC1/rinse/HF/rinse/dry process

Watermarks for a non-optimized cleaning and drying process on an 82 nm deep trench isolation structure on a 300 mm wafer.

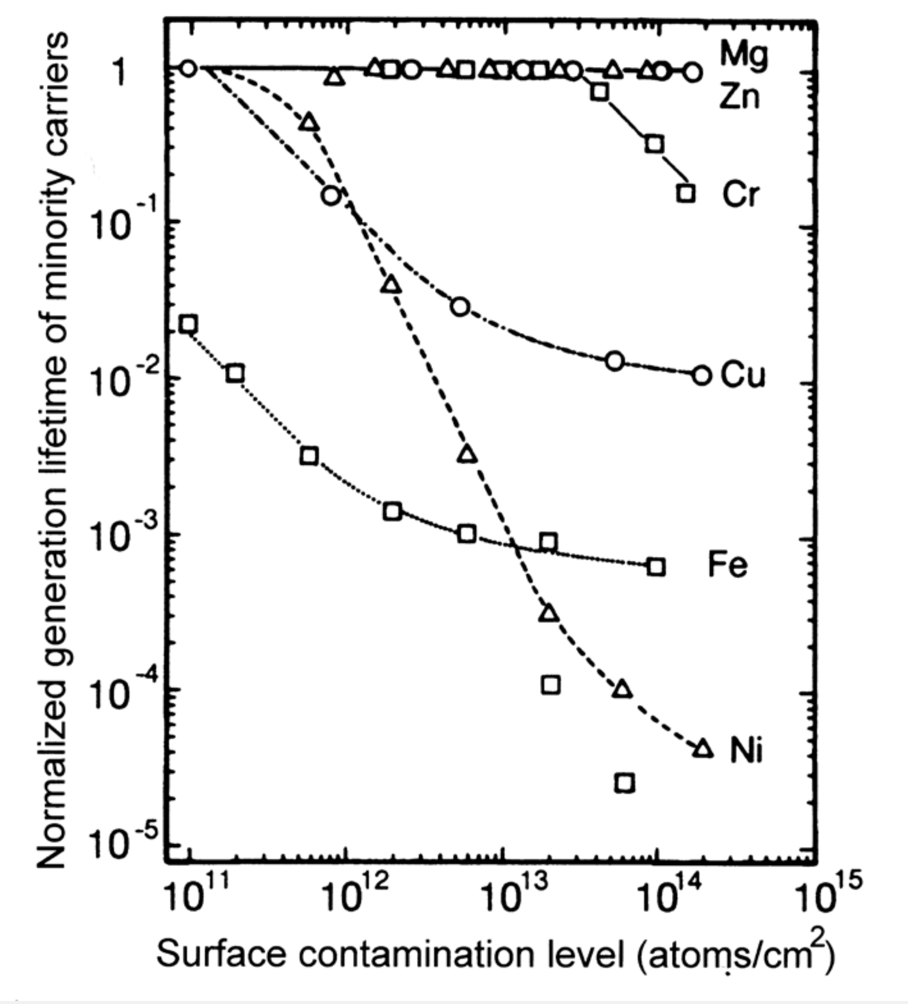


Metal contamination sources

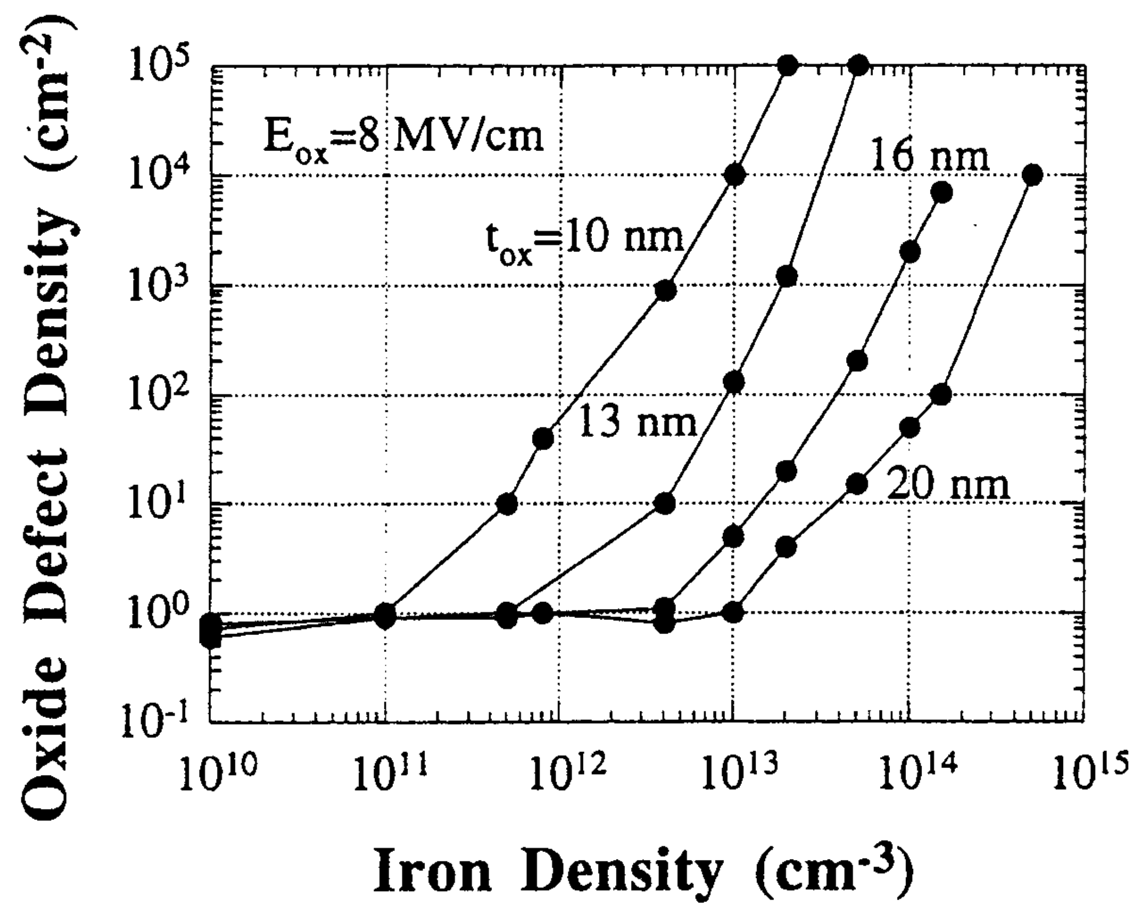
- -structural parts of equipment (e.g. shutter blades)
- -piping for gases and liquids
- -tweezers and jigs
- -sweat (esp. sodium)
- -chemicals
- (some photoresist developers are dilute NaOH !)

- Requirements for metal contaminants have not changed since the 1997 ITRS!

Carriei lifetime in <Si>



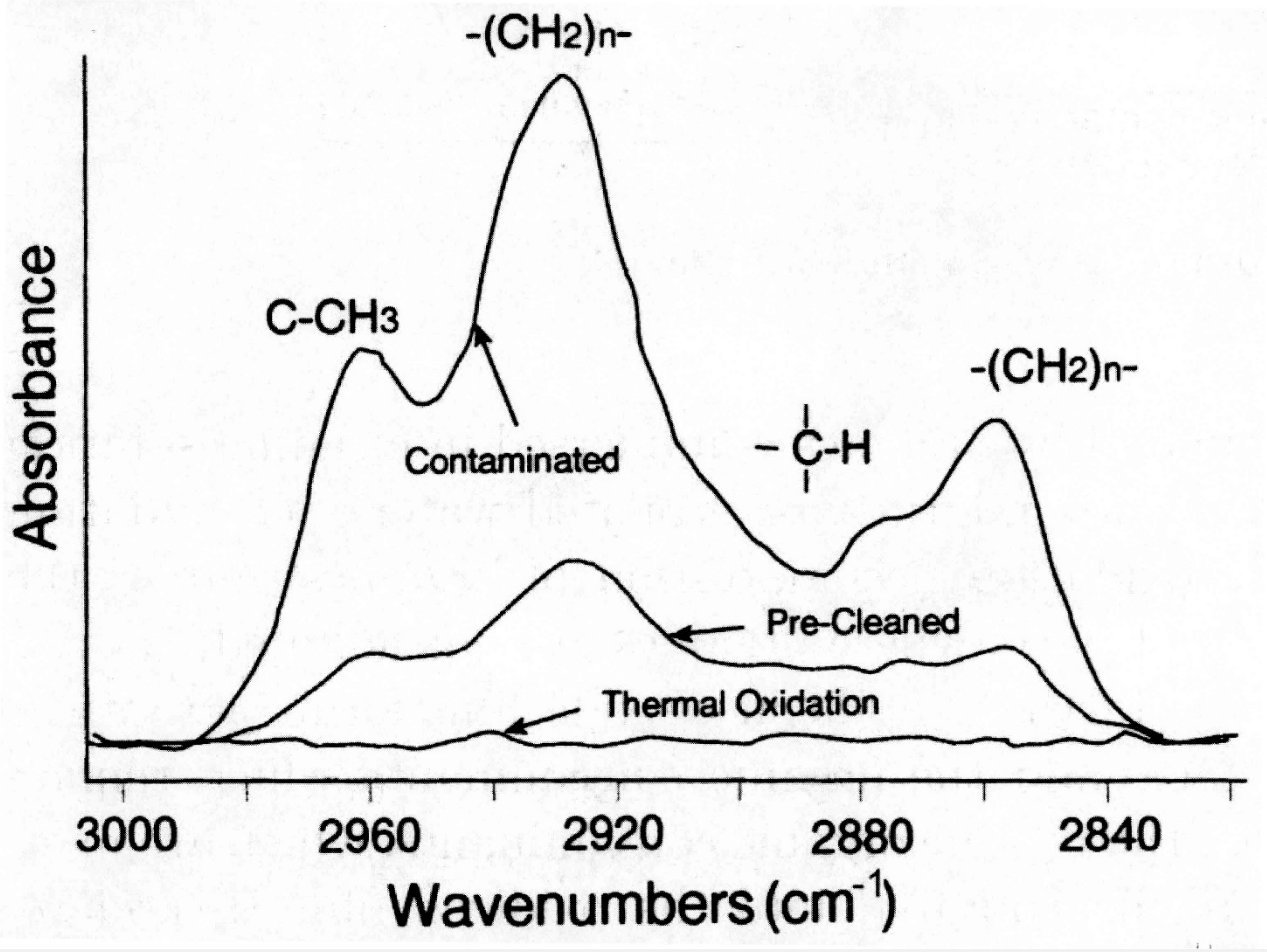
Iron contamination



Source of organic contamination

- -solvent vapors (e.g. HMDS priming and resist baking)
- -wafer boxes
- -etch and deposition gases (e.g. n CF_4 ==> $(CF_2)_n$ + 2nF*)
- -outgasing from spin-on films
- -vacuum pump oils (backstreaming to process chamber)
- -equipment O-rings
- -cleanroom construction materials (wall seals, filter fan unit seals)

IR spectra of clean and contaminated surfaces



Finishing clean

- In situ NF_3/NH_3 remote plasma preclean
- Ar sputter preclean

- Remember about sputtering of chamber walls!

Physical cleaning

- Brush scrubbing (after scribing, CMP)
- Jet scrubbing (danger of electrostatic charge)
- Ultrasonic (kHz) / megasonic (MHz) (danger of wafer damage, structure detaching)

Typical methods for analysis of wafer

Object	Analytical method
Particles	Laser scattering, SEM, EMPA, AES
Metals	TXRF (total reflection X-ray fluorescence), GFAAS (grafite furnace atomic absorption spectroscopy), ICP-MS
Organics	FTIR, TDS, TOF-SIMS
Moisture	TDS (thermal desorption spectroscopy)
Native oxide film (terminated states)	XPS, FTIR, TDS
Microroughness	AFM, STM, laser scattering

Cleanrooms

- Concept and standards
- Design and air circulation
- Subsystems
- Hazards and alarms

When feature widths were far greater than about 10 µm, purity was not the issue!

Cleanroom

(Berkeley Lab)

Do we need cleanroom?

- Expenssive
- Large in size
- Fire, toxicity hazards
- Special overall for operators
- Special staff to support all systems

- Mini-Environments:
  - load wafers and take out ready chips

Cleanroom concept

- A cleanroom is an environment, that has a low level of pollutants under very stable ambient conditions
- The air entering a cleanroom from outside is filtered to exclude dust, and the air inside is constantly recirculated through High-Efficiency Particulate Air (HEPA) and Ultra-Low Penetration Air (ULPA) filters to remove internally generated contaminants
- Some cleanrooms also control humidity, temperature and pressure
- All users of cleanroom use special suits to protect the devices from human contamination

Two cleanliness & safety goals:

1) protecting wafers from people and other contamination sources

2) protecting people from hazardous chemicals and gases

Protecting people

Potential danger

-acids and bases
-resists, solvents, pump oils
-gases
-ionizing radiation
-UV-radiation
-fires

Protection

- safety training
- safety goggles
- safety gloves
- safety apron
- working discipline

Protecting wafers

- Unwanted atoms must not move around the lab.

- Because of diffusion, high temperature processes are especially quick to move stuff around.

Solutions:

Processing in dedicated space & equipment.
(Outside cleanroom if necessary).

Cleaning before next step. Where ?

ISO 14644-1 cleanroom standards (particles)

Class	maximum particles/m³ ≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	FED STD 209E equivalent
ISO 1	10	2					
ISO 2	100	24	10	4			
ISO 3	1,000	237	102	35	8		Class 1
ISO 4	10,000	2,370	1,020	352	83		Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	Class 1000
ISO 7				352,000	83,200	2,930	Class 10,000
ISO 8				3,520,000	832,000	29,300	Class 100,000
ISO 9				35,200,000	8,320,000	293,000	Room air

US FED STD 209E class 1 (1 particle >0.5 µm per cubic foot) cleanroom.

Feature	**Values**
Cleanliness, process area	< 35 particles/m3, > 0.50 µm
Temperature, lithography	22ºC ± 0.5
Temperature, other areas	22ºC ± 1.0
Humidity, lithography	43 ± 2 %
Humidity, other	45 ± 5 %
Air quality	
total hydrocarbons	<100 ppb
NO_X	<0.5 ppb
SO_2	<0.5 ppb
Envelope outgassing	6.3×10^{-8} torr·l/(s·cm^2)
Pressure	typical 30 Pa relative to outside
Acoustic noise	< 60 dB
Vibration	<3 µm/s (8-100 Hz)
Grounding resistance	1 MOhm
Magnetic field variation	< ± 1 mGauss (Earth 400 mGauss)
Charging voltage	< ± 50 V

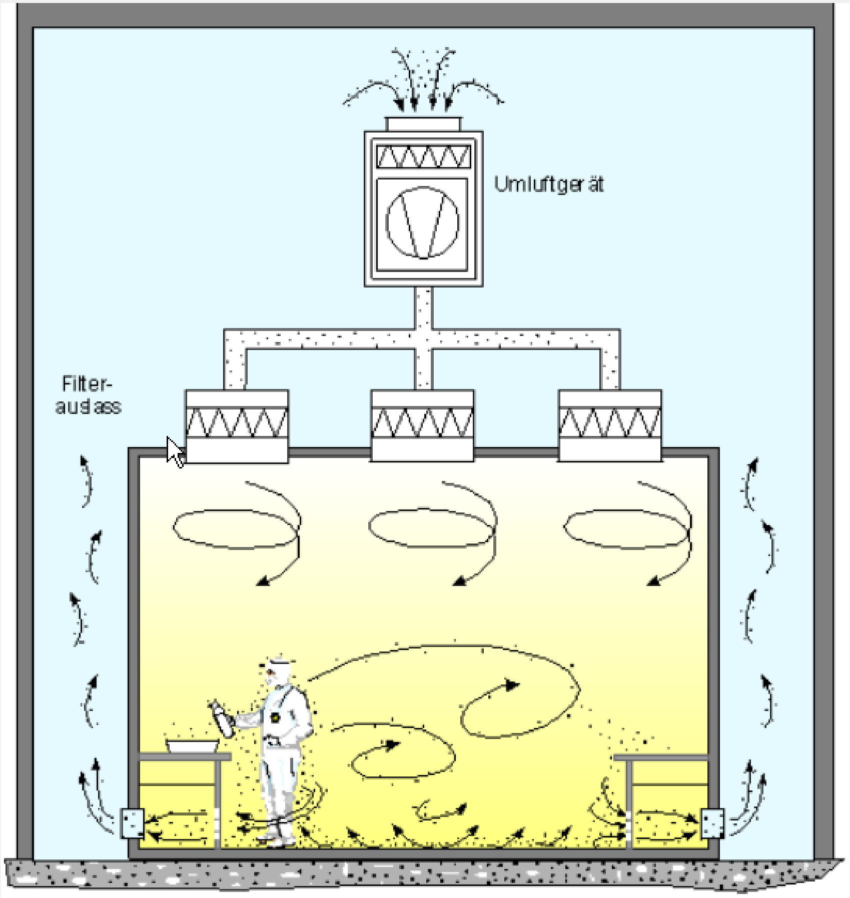
Cleanroom construction requirements

- construction
  - minimum vibrations
  - overpressure, to avoid outside flows
  - mechanical and electrical interference minimization
- materials
  - easy cleaning
  - no outgassing
  - no contamination
- air handling
  - particle cleanliness
  - chemical purity
  - temperature
  - humidity
  - laminar flow

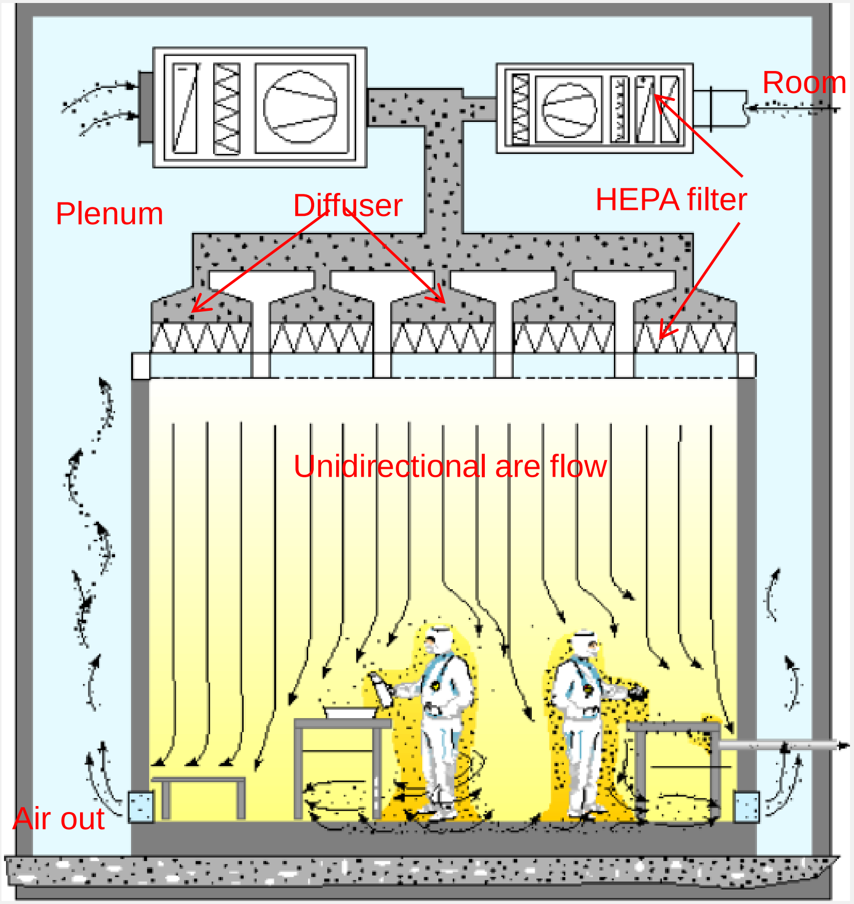
Possible air flows in a cleanroom

Paritcle deposition rate *J=nu*,
u – settling velocity (0.001 cm/s),
i.e. 0.1 particle per sq. m per s

Turbulent

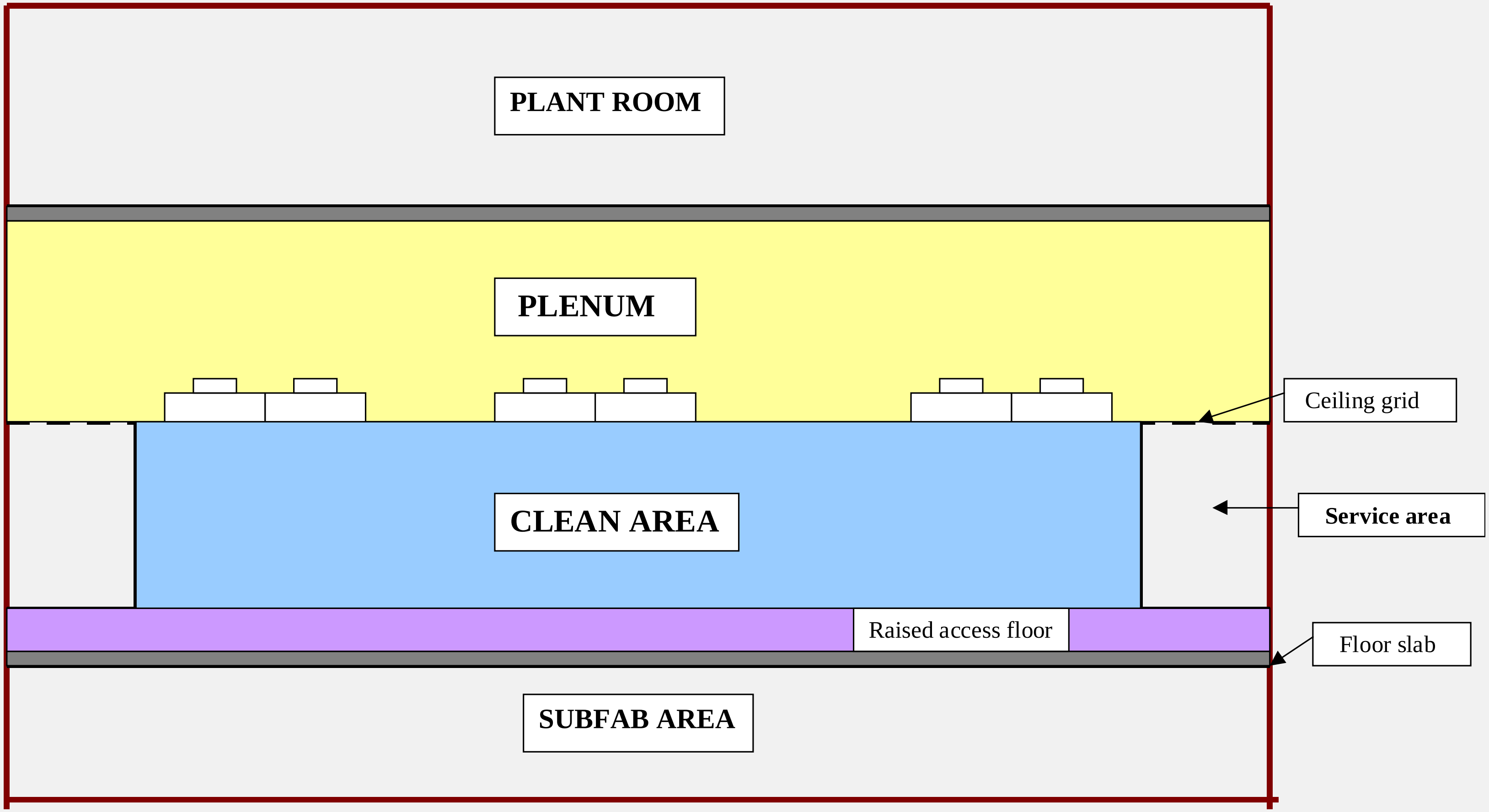


Laminar

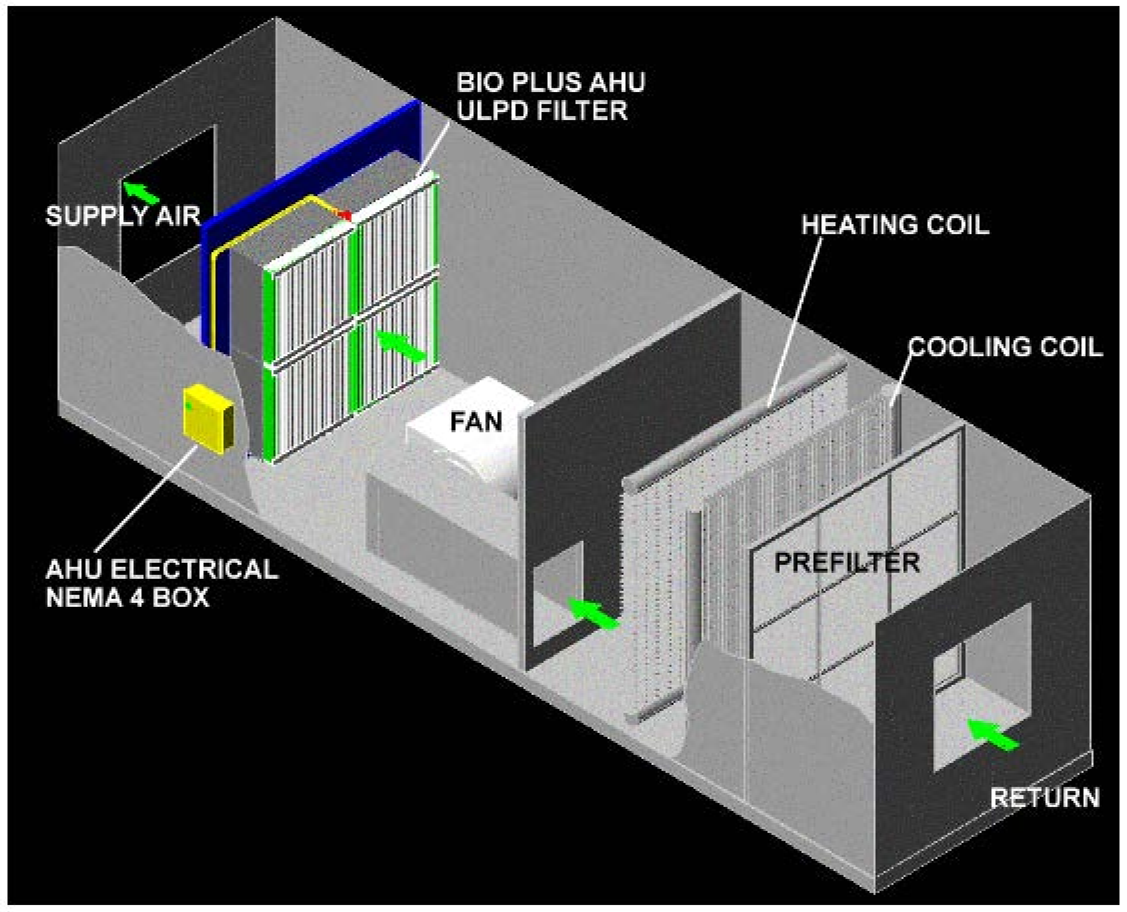


Air extract places

Cleanroom design

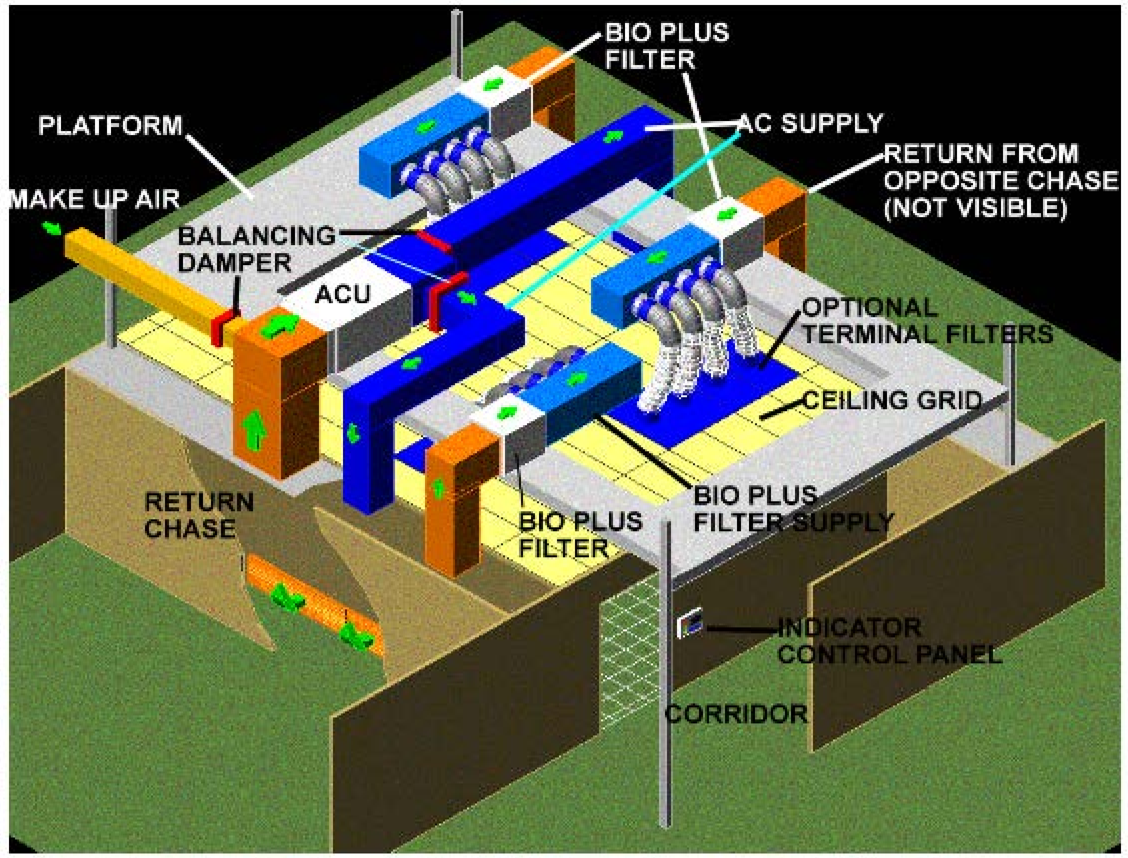


Air handling unit

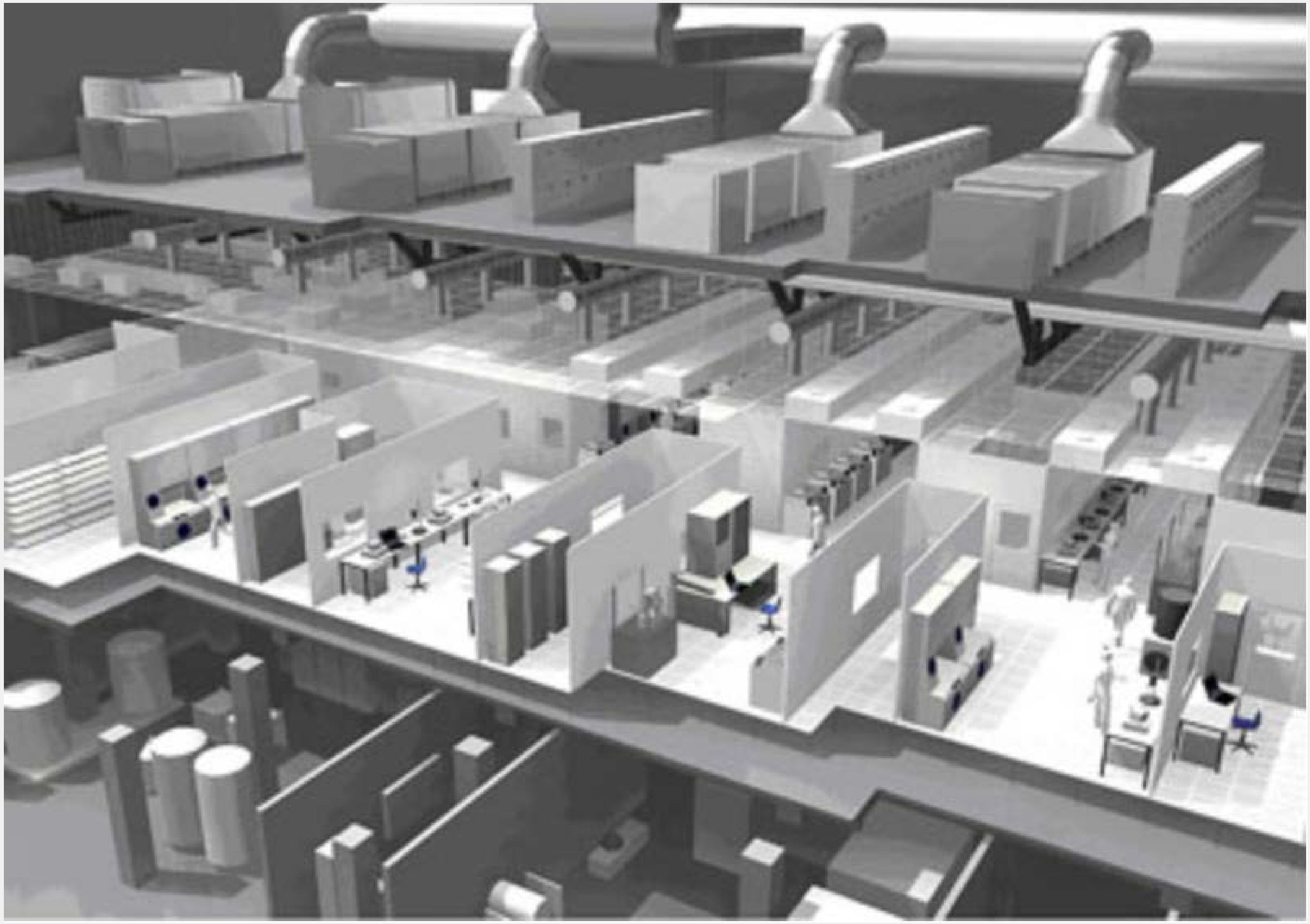


Air facilities

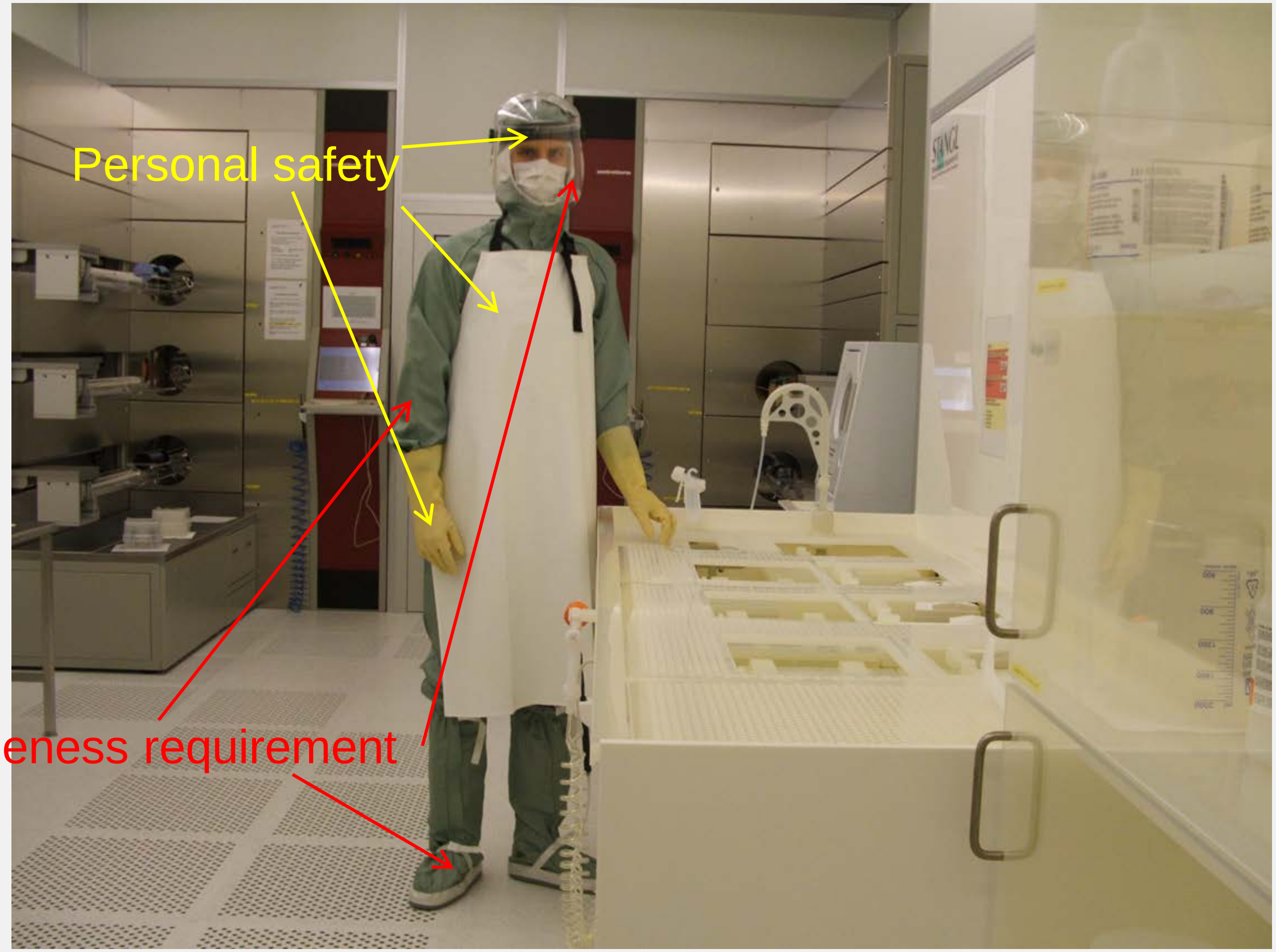
Extraction, conditioning, recirculation (500 air changes per hour), filtration



MICRONOVA cleanroom



Inside of MICRONOVA cleanroom



Personal safety

Cleanleness requirement

Cleanroom subsystems

- DI-water (UPW) stands for deionized and ultrapure water
- liquid drains
  - - acids & bases
  - - solvents
  - - HF
- vapor exhausts
  - - acids & bases
  - - solvents
- gas supply:
  - - house gases: N_2, O_2, Ar, compressed air
  - - specialty gases: SF_6, SiH_4, N_2O, Cl_2
- gas abatement
- gas alarms
- fire alarms

Environment, safety and health (ESH)

- **Radiation**
  - implanter (X-rays, gamma-rays)
  - plasma tools (microwave energy, UV-radiation)
- **High temperature**
  - hot plates, furnaces
- **Toxic gases**
  - implanter, CVD, ALD
- **Wet chemical hazards**
  - wet etching, wafer cleaning, plating baths
- **Fire**
  - detection, extinguishing

Gases

- H_2 explosive
- SiH_4 self-igniting
- PH_3 toxic
- AsH_3 toxic

Chemicals

- corrosive chemicals (acids, bases)
- strange corrosive chemicals (HF)
- hot chemicals (80^{o}C baths)
- toxic chemicals (old resist solvents)

Fires

- Lots of hot chemical baths
- Lots of high temperature equipment
- Lots of electrical equipment

- Cannot use powder extinguishers !!
- Even small amount of smoke will cause major damage

Other safety matters

- UV from plasmas
- X-rays from ion implantation
- high voltage (200 kV in I/I)
- solvent vapors

- Spills and leaks can be anywhere !

Conclusions

- Microfabrication is impossible without cleaning (surface preparation)
- Wafer cleaning provides active cleaning
- Microfabrication is impossible without cleanroom environment
- Cleanroom (and its subsystems) provide passive cleanliness
- A cleanroom is expensive in construction and in maintenance